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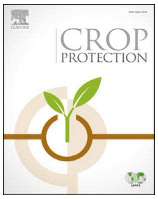

Volumetric validation of mass balance using a computational phase Doppler approach for disc core nozzles

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ABSTRACT

The mass balance of orchard air-blast sprayers has historically been assessed using an array of samplers to capture airborne particles. However, these methods only provide an idea of flux with no other information which is pertinent to understand the movement of droplets and their potential to drift. While droplet analysis for agricultural sprayers has always been conducted in a laboratory setting with the use of laser devices, a new phase Doppler approach is being explored to assess droplet spectra, velocity, and flux in outdoor field conditions. Therefore it is the objective of this study to develop a methodology and the potential limitations for using a phase Doppler system while in a laboratory setting. Due to the expected variability of field conditions as well as the turbulence of orchard sprayers, a computational approach was sought to assess flux from a single scan of a conical spray plume's diameter. Using a constant scanning speed of 0.0079 m/s, a disc core (D1/DC33) hollow cone nozzle was examined at 310, 410, and 520 kPa pressure at five different heights (10, 20, 30, 40, and 50 cm). Computational flux was then compared to the actual flow rate, finding a −3.3% average error with a range of −16.9% and 4.7% illustrating a small underestimation of mass with the phase Doppler which was related to distance and droplet frequency. Further, comparisons were also assessed including pattern/symmetry, droplet spectra, velocity, and the overall number of samples. The proposed methodology indicates potential for the use of phase Doppler technology for *in situ* measurements of spray equipment using a conical-type spray nozzle, such as that of the orchard air-blast sprayer.

1. Introduction

The axial-fan air-blast sprayer is the most common device for agrochemical application for tree, bush and vine crops. The air produced from the fan propels the droplets into the canopy, assisting in the necessary canopy penetration and deposition. This also carries a greater risk to place drift-prone droplets into the air for potential transport downwind. When assessing these sprays in the field, it is typical to use collection samplers such as cotton ribbons, high-volume air samplers, impingers, monofilament fishing line, nylon cords, Petri dishes, plastic fallout sheets, polyurethane foam, mylar sheets, and rotating rods (Bui et al., 1998; Salyani et al., 2006). With each collector type, potential risk of inaccuracy is heightened due to differing collection efficiency. For instance, Egner and Campbell (1960) reported that sub-100 μm droplets were the most affected by the diameter of a collector, showing that the smallest 2.5 mm diameter strings had collection efficiencies of only 74%. This droplet class is essential to drift research and is also important to the mass balance. Furthermore, accurate droplet information is essential when examining and predicting the performance of agricultural nozzles. For example, small droplets provide better coverage but quickly lose their inertia, sometimes causing an undesired result (i.e. drift, evaporation, and/or deposition on off-target locations). Larger droplets are often used to counteract these phenomena, however these droplets may also provide less coverage and are also likely to have unintentional deposition by run off, shattering, and/or bouncing off the leaf surface (Dullenkopf et al., 1998; Forster et al., 2005; Schou et al., 2012).

Droplet data are also useful for modelling spray drift and deposition by understanding the droplets' size distribution and their interaction with meteorological conditions (i.e. temperature,

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humidity, wind speed and direction, etc.). To acquire these spray plume characteristics, one or more of these common methods are typically used: laser diffraction, Particle Measuring Systems (PMS), and phase Doppler interferometry (PDI), also referred to as phase Doppler particle analyser (PDPA) or phase Doppler analyser (PDA). These methods are largely accepted within spray industries, though each technology provides different distributions, especially in dense, poly-disperse sprays such as in agricultural applications (Parkin, 1993). However, while these laser technologies provide droplet distributions, only the PDI directly provides velocity and flux measurements which are important to determine the mass balance of a nozzle. As discussed by Goguen et al. (1997), by understanding the fluxes of a plume, a better knowledge of the mass balance will be obtained. The importance of this work is to verify PDI can give mass flux in agricultural sprayers, which have much smaller mass fluxes than combustion sprayers where optical diagnostics are often optimized.

Historically, the mass of a spray plume in laboratory settings has been assessed by traversing a nozzle over a stationary PDI system. The nozzle stops at discrete locations thereby accurately mapping the plume with a differentiation of droplet sizes, velocity, and flux at each coordinate. These laboratory PDI systems are comprised of two pieces of equipment which (with few exceptions) must stay stationary to keep transmitter and receiver in alignment. In 2008, the F/PDI (Artium Flight-PDI, Artium Technologies, Inc, Sunnyvale, California, USA) for *in situ* cloud droplet analysis was introduced which combined the transmitter and receiver into one enclosed system, allowing the technology to be taken out of the laboratory and separating itself from laser diffraction (Chuang et al., 2008). In 2011, Artium, with collaborative effort of Lincoln Agritech, Ltd. (Lincoln, New Zealand), developed the Demeter probe to assess sprays from agricultural sprayers (Hewitt et al., 2013). It is the Demeter probe which is used in this study.

Past research has varied substantially in the setup and analysis of agricultural sprays with phase Doppler technology (Table 1). Each author, depending upon their specific objectives, phase Doppler system, and laboratory capabilities had a specific method for obtaining their data. It is important to note that there is no standard for sampling procedure or system specifications. For instance, the droplet and velocity range is directly related to the fringe spacing and sampling volume which is determined by a number of hardware decisions including the light scatter angle, the optical focal length, various optical lenses, and the chosen beam separation (Bachalo and Houser, 1984; Tuck et al., 1997), however these setting are not always stated in the literature. In previous laboratory work (summarized in Table 1) the light scattering angle and focal length range between 30 to 70° and 310 to 1000 mm, respectfully. With these settings, the maximum droplet diameter achievable varied between 451 and 1000 μm.

Most authors only use the PDI to make measurements near the nozzle to find the drop size distribution, either for the purpose of initializing a simulation or to relate the drop size distribution to the measured drift in the field. However, with a sufficiently long traversing system, the PDI can also provide the mass distribution, much as a patternator would, while also providing drop size information along the width of the spray, which is important for efficacy.

However, no methods have been established to assess agricultural sprays *in situ* using PDI technology and it is hoped that this work will be the building blocks for more comprehensive mass balance research for in-field analysis. Also, with the ability to move the PDI from its historically static position, previous practices may no longer be applicable. Therefore, it is the objective of this study to establish and validate a preliminary methodology for assessing spray characteristics, such as pattern, distribution, velocity, and flux, in a relatively controlled environment to determine what is feasible for in-field analysis by means of traversing the PDI probe non-stop through a conical spray plume that is typical of such orchard sprayers.

2. Materials and methods

2.1. Spray analysis setup

A schematic of the test facility is shown in Fig. 1. One of the objectives of the current study is to demonstrate that the PDI could

Table 1
Examples of past research and variations of methodologies between phase Doppler systems.

Citation	Phase Doppler system	Size maximum (μm)	Distance from nozzle (cm)	Counts (#)	Liquid pressure (kPa)	Traverse/Static	Traversing speed (m/s)	Voltage
Chapple et al. (1993)	Aerometrics PDPA	800	30	*	276	T	0.0025	325
Chapple et al. (1995)	Aerometrics PDPA	700	20–30	<200–30,000>	207–276	T/S	0.0025	325
Dullenkopf et al. (1998)	Aerometrics PDPA	*	10	≥10,000	500	S	N/A	*
	DANTEC DualPDA	*	10	≥10,000	500	S	N/A	*
	Qiu and Sommerfeld PDA	*	10	≥10,000	500	S	N/A	*
	Aerometrics PDPA	*	10	≥10,000	50	S	N/A	*
	DANTEC DualPDA	*	10	≥10,000	50	S	N/A	*
	Qiu and Sommerfeld PDA	*	10	≥10,000	50	S	N/A	*
Miller et al. (2008)	*	*	35	*	300–450	T	0.020	*
	*	*	35	*	200	T	0.020	*
	*	*	35	*	250	T	0.020	*
Nuyttens et al. (2007a) [a]	Aerometrics PDPA	1000	50	≥10,000	200–450	T	0.025	*
	Aerometrics PDPA	1000	50	≥10,000	200–450	T	0.017	*
	Aerometrics PDPA	1000	50	≥10,000	200–450	T	0.030	*
Nuyttens et al. (2009) [a]	Aerometrics PDPA	1000	50	≥10,000	200–400	T	0.025	*
	Aerometrics PDPA	1000	50	≥10,000	300	T	0.025	*
	Aerometrics PDPA	1000	50	≥10,000	0.00	T	0.025	*
Sidahmed et al. (1999)	Aerometrics PDPA	875	4	10,000	207	S	N/A	*
	Aerometrics PDPA	875	4	10,000	207	S	N/A	*
Tratnig and Brenn (2010)	Dantec	451	8	20,000	750–15,200	S	N/A	*
Tuck et al. (1997)	Dantec	900	35	24,000	300	T	0.001	*
Wolf et al. (1995)	Aerometrics PDPA	1020	45	10,000	200	T/S	0.020	350
Farooq et al. (2001)	Aerometrics PDPA	552	5–30	20,000	275	S	N/A	310
Womac et al. (1999)	Aerometrics PDPA	*	50	10,000	200–450	S	N/A	*

[a] PDPA specifications were cross-referenced in Nuyttens et al. (2006).